Synthesis of Linear Antenna Array Using Genetic Algorithm to Reduce Peak Sidelobe Level

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Abstract

In antenna design, it is important to optimize the amplitude weights of a linear antenna array to achieve low peak sidelobe level (PSLL). This paper deals with a linear inequality constraint on array factor to get maximum response in look direction and reduced sidelobe levels in a specified stop band region. Linear regular array as well as thinned linear array is optimized using a constrained genetic algorithm (CGA). The convergence of the optimization algorithm is also reported and its utility is shown in getting a desired antenna beam pattern with fewer radiating elements. Thinning is achieved by iteratively applying CGA which results in reducing the number of elements by 28% and overall transmitted energy by 27%, keeping a specified beam width first null (BWFN) with considerable reduction in PSLL.

1. Introduction

The design objective of a phased array antenna for radar and communication is to attain a directive pattern through optimum weighting. In the radar beamforming system it is desired to lower the sidelobe level of the beam pattern to suppress the interferer entering from sidelobes and to reduce the power transmitted in the sidelobe. Another objective is to reduce the energy transmitted by developing an array with fewer elements that fulfills the requirements of a full regular array through the reduction of the effective number of radiating elements. So the researchers have figured out ways to suppress peak sidelobe level using different optimization techniques such as simplex algorithm [1, 2] and genetic algorithm [3-17]. While reducing PSLL it is also desired to maintain the first null width within a specified region.

In [1] a set of linear inequality constraints is developed which specifies a desired stop band region and the problem is solved using simplex algorithm. Many techniques are proposed previously to achieve sparseness. In [2] a simplex search algorithm is implemented to get a non-uniformly spaced array having minimum number of elements. The work presented in [3] gives us the motivation to run genetic algorithm iteratively to obtain sparseness starting with a full regular array with spacing of 0.5λ. Latest research is carried out in favor of implementing GA to optimize amplitude weights of the array [4-8].

GA has also been designed to work for Distributed Random Antenna Array (RAA) [9], where the position of elements cannot be manipulated. Previous research is based on modifying GA to obtain shaped beam patterns [10, 11]. Genetic Algorithm has also been implemented to introduce nulls at the specified locations [12, 13]. In papers [14-17], different approaches are discussed to achieve sparseness and thinning of antenna array using genetic algorithm.

In this paper it is assumed that the initial elements spacing is 0.5λ and elements are uniformly illuminated initially. A set of linear inequality constraints are imposed on the genetic algorithm objective function to maintain first null width and the stop band region. The scope of the work is to reduce the PSLL as compared to that obtained through uniformly illuminated array and to get minimum possible number of radiating elements by keeping the PSLL in the desired range, hence reducing the effective aperture and transmitted energy.

The sequence of the paper is as follows. The proposed optimization algorithm which is genetic algorithm is discussed in detail in section 2. In section 3 the formulation of objective function and the linear inequality constraints are developed for linear array. In section 4 the problem of developing a sparse array through iterative constrained genetic algorithm is addressed. The simulation results of both regular and thinned linear arrays are given in section 5. Finally the conclusion and achievements are discussed in section 6.

2. Genetic Algorithm

Genetic Algorithm belongs to the family of evolutionary algorithms which models the search process as an evolution by means of natural selection. GA is preferred over other optimization techniques since it searches a wider space and locates the global minimum rather than terminating on achieving the local minima as in the case of simplex method [2].

The concept behind optimization through genetic algorithm (GA) involves selection of parents (pairs of points) from a random sample on the basis of their fitness function value, which recombine to generate new offspring. First the offspring are mutated and the best of them are selected for next generation, which is a step towards locating the minimum. There are many parameters in genetic algorithm that need to be adjusted according to the application to achieve global minimum such as the population size, number of generations, type of mutation, crossover and selection functions.

In this paper the stopping criterion for genetic algorithm is the maximum generations limit. A tradeoff is made on the population size so that it searches a wider region in parameter space, thereby reducing the chance of settling for a local minimum rather than a global one. However, at the same time, the population size is not set to be too high in order to achieve a decent convergence rate. The initial population score is such that the array weights are uniformly distributed. The mutation function is selected to be mutation adapt feasible that chooses a direction and step length that satisfies the bounds and the linear constraints. The following flow chart gives brief overview of the optimization procedure to obtain the solution.

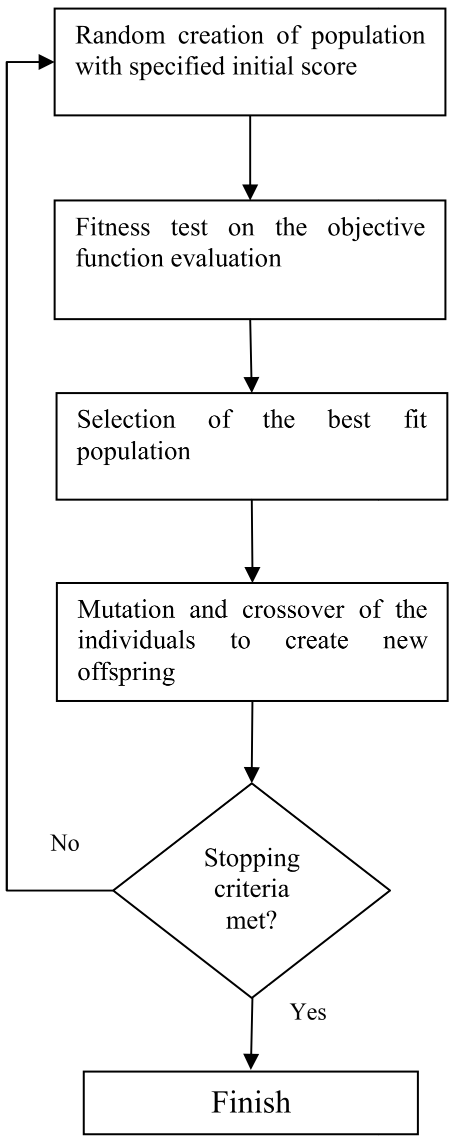

Fig.1. Genetic Algorithm Flowchart

Figure (1) summarizes the sequence of steps involved in the optimization procedure via GA. In section 4, detailed description is given to obtain array thinning using genetic algorithm. In section 5 where the simulations results are provided, the parameters values are specified that are utilized in genetic algorithm to achieve desired solution.

3. Problem Formulation

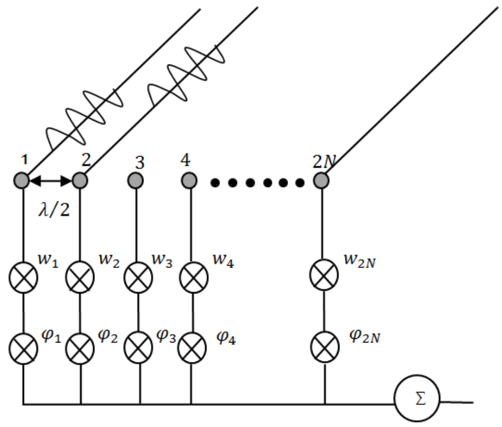

Fig.1. Linear Antenna Array

Fig.2 models a linear antenna array with 2N elements having an inter element spacing of $\lambda/2$ to minimize mutual coupling effects. The signal picked up by each individual array element is shifted in time which is adjusted accordingly by the phase weights φ_n associated with each element. Desired aperture illumination and beam shaping is achieved through amplitude weights w_n. Initially the array has equal amplitude weights w_n across all its elements making it a uniform array. Antenna array pattern is determined by its array factor that has a following relationship:

$$AF(\theta,\varphi) = \sum_{n=1}^{2N} w_n e^{j\,\vec{k}.\vec{x_n}} \qquad (1)$$

Where k is the wavenumber $|k| = {}^{2\pi}/_{\lambda}$.For symmetric and linear array with real weighting we have array pattern as:

$$AF(\theta,\varphi) = 2\sum_{n=1}^{N} w_n Cos\left(\frac{2\pi}{\lambda} * \sin\theta * x_n * \cos\varphi_n\right) \qquad (2)$$

In case of linear array and beam pointing at the broadside of array with $\varphi = 0$, the contribution of amplitude weights directly affects the array response.

$$AF(\theta) = X(\theta)^T w \qquad (3)$$

We desire a directive pattern that has narrow main beam and low sidelobes. As the problem is formulated in [1], the minimization of weights is subjected to suppression of array factor in stop band. Here we are considering getting a normalized array factor in pass band (w_p) and minimum possible level in stop band region (w_s).

The objective function is formulated for genetic algorithm and the linear constraints are established such that we get normalized response in the desired band and ripples in stop band.

$$\begin{aligned} & \underset{w}{minimize} \quad x * C \\ & subject\ to \\ & \qquad Ax^T \le b \end{aligned} \tag{4}$$

x is a vector of length 1x $N+1$ containing w and δ_s. So w is the amplitude weight vector of length 1x N and δ_s gives sidelobe level attenuation. In this paper the array is assumed to be symmetric where the number of linear array elements is $2N$. Array factor is discretized into M points. C is $(N+1)$ x 1 , b is $(2M+1)$ x 1 and A is a matrix of length $(2M+1)$x $(N+1)$.

$$fitness\ fun = (w \quad \delta_s) \begin{pmatrix} 0 \\ \vdots \\ 0_N \\ 1 \end{pmatrix} \tag{5}$$

$$subject\ to \tag{6}$$

$$\begin{pmatrix} 1 & \cdots & 1^N & 0 \\ -1 & \cdots & -1^N & 0 \\ X(\theta)^T & \cdots & X(\theta)_N^T & -1 \\ -X(\theta)^T & \cdots & -X(\theta)_N^T & -1 \end{pmatrix} \begin{pmatrix} w \\ \delta_s \end{pmatrix} \le \begin{pmatrix} 1 \\ -1 \\ 0 \\ 0 \end{pmatrix}$$

4. Application of Iterative Genetic Algorithm for Thinning

Following are the sequence of steps involved to iteratively apply genetic algorithm to get minimum number of radiating elements.

1) Select a fixed length linear array having an inter element spacing of 0.5λ and that is assumed to be symmetric. In our case we have taken the number of elements of linear array 2N=128.
2) Construct linear inequality constraint of maximizing the normalized array factor in the passband and minimizing the sidelobes in specified stop band region, which is set to be θ = [2:90].
3) Run genetic algorithm with initial population score in first iteration such that array elements are uniformly illuminated.
4) Find the peak side lobe level (PSLL) obtained through new weights obtained by running the algorithm for specified number of generations that is set to be 500.
5) If the PSLL is less than the prescribed limit remove some elements whose weight is less than 0.25*max weight or the element with the lowest weight.
6) Run the genetic algorithm again with the initial population of the remaining weights of the elements after the removal process.
7) Repeat 5 but if PSLL comes out to be greater than the prescribed limit insert elements that are exactly the midpoint from the last two successive runs. Assign arbitrary positions to the inserted elements with uniform weights and run the genetic algorithm again.

5. Simulation Results

The simulation for optimization algorithm is run using Matlab R2013a genetic algorithm tool box with a population size of 50 and stopping criteria is defined in terms of maximum generation's limit which is set to be 500. The algorithm is implemented firstly on a regular linear antenna array to get optimum weights and lowest possible peak side lobe level (PSLL) and secondly the algorithm is applied as mentioned in section 4 to achieve sparseness, reduced aperture and energy.

5.1. Linear Antenna Array

The array length is 2N=64 with M=512 pts. The stop band region is defined to be $\theta = [3:90]$. The algorithm runs for 500 generations and PSLL obtained is -38 dB maintaining the BWFN requirement of 3° as shown in Fig.3. The optimum weights obtained after 500 iterations is listed in table 1. A uniformly illuminated array pattern is also plotted in Fig.4. Fig.5 shows the amplitude distribution of the symmetric antenna array and and the convergence plot is shown in Fig.6.

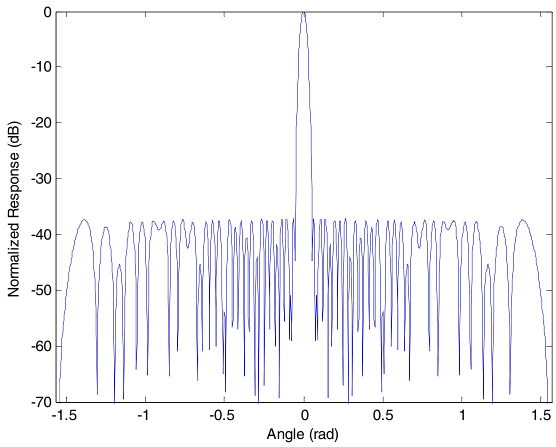

Fig. 3. Antenna Array Pattern obtained through weights optimization by genetic algorithm and PSLL = -38dB.

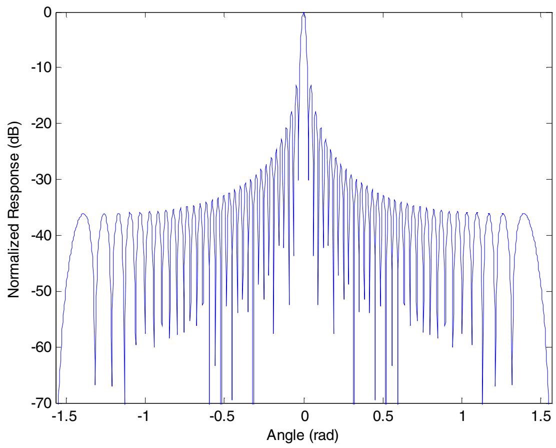

Fig. 4. Antenna pattern of uniformly illuminated 2N=64 elements having PSLL = -13.2dB.

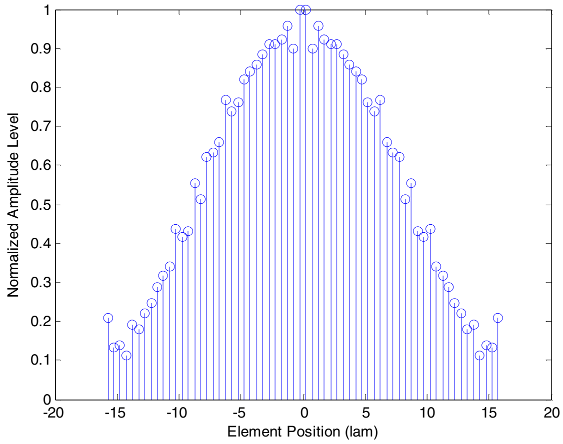

Fig. 5. Amplitude distribution of weights for 2N=64 elements through genetic algorithm.

Fig.5 represnts the amplitude distribution across 64 elements of the array. Since the array is symmetric so the amplitude levels are same for symmetric elements. The sidelobe levels of optimized patterns are of same height. The main beam of the optimized pattern is wider than that of uniformly distributed pattern shown in Fig.4.

5.2. Thinned Array

The thinning of array is achieved through iteratively applying genetic algorithm starting from a full regular linear array of size 2N=128. The steps are summarized in section IV. Our algorithm puts linear constraint of maintaining the BWFN. The results are tabulated in table 1. The simulation results show that after 10 iterations thinning of 28% and power consumption of 27% is achieved while keeping the PSLL at -32 dB and BWFN at 2 deg. Fig.7 depicts the array pattern obtained after 1st iteration and the corresponding weights distribution is shown in Fig.8. When the number of elements removed is greater than 18 which occurs at i=10, then the optimization is stopped and thinned array is achieved that has an array pattern shown in Fig.9 having the optimized weights of Fig.10.

Table 1. Thinning of array using iterative constrained genetic algorithm.

Iter No.	N	PSLL (dB)	Radiated Power	BWFN (deg)
1	64	-32.0882	40.3505	2
2	57	-28.5959	38.1003	2
3	55	-29.8325	37.0176	2
4	54	-30.9688	36.2207	2
5	53	-31.6122	35.1626	2
6	52	-32.0955	34.2348	2
7	51	-32.1622	33.0024	2
8	49	-32.2821	32.4288	2
9	48	-32.2288	28.9436	2
10	46	-31.8489	29.4609	2

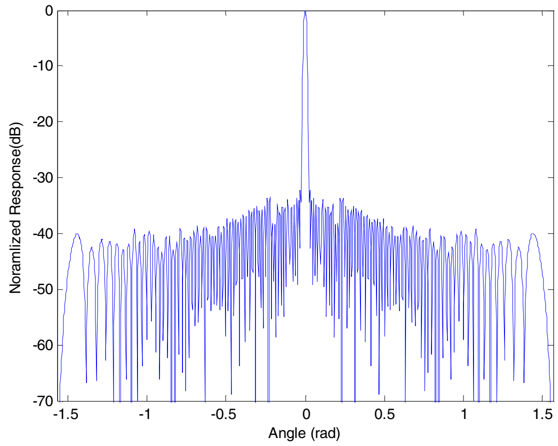

Fig. 7. Linear Antenna Array Pattern for 2N=128 and PSLL=-32 after 1st iteration.

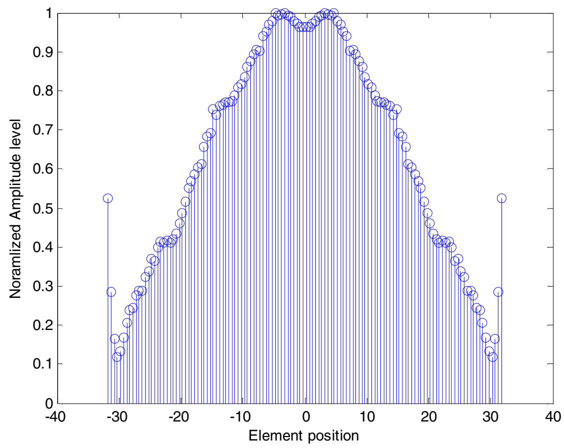

Fig.8. Weights distribution after 1st iteration against element position.

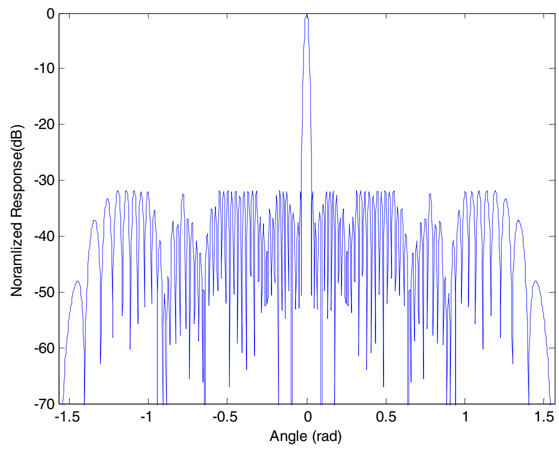

Fig.9. Thinned Antenna Array Pattern with 2N=96 and PSLL=-31.8dB.

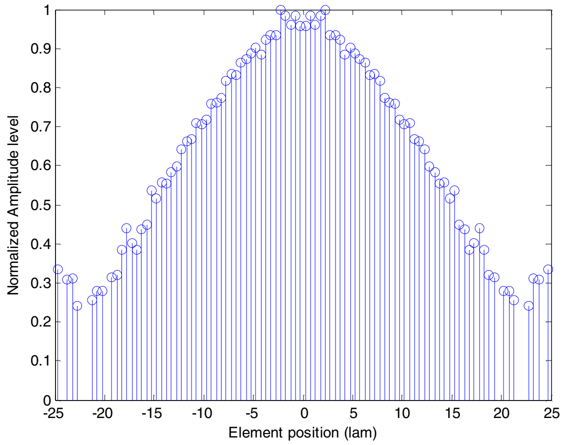

Fig. 10. Amplitude distribution of the weights obtained for thinned array after 10th iteration.

The optimized pattern for full regular array is shown in Fig.7 and the array pattern obtained after array thinning in Fig.8. From the comparison of both plots it can easily been seen that the peak sidelobe and main beamwidth remains same. Fig.10 shows the amplitude distribution of thinned array where the effective aperture is reduced from that of full regular array shown in Fig.8.

6. Conclusion

We propose an approach to achieve a reduction in the peak sidelobe level (PSLL) of linear antenna array. Genetic algorithm based optimization is shown to accomplish thinning keeping a specified beamwidth first null position. As shown in section 5, reduction in peak sidelobe level is obtained and then maintained while array thinning of 28% and overall energy reduction of 27% is achieved.

7. References

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